COMPARISON OF RATES OF DARK ADAPTATION UNDER RED ILLUMINATION AND IN TOTAL DARKNESS

R. H. Lee

Naval Medical Research Institute
Bethesda, Maryland

30 December 1943

NAVAL MEDICAL RESEARCH INSTITUTE
NATIONAL NAVAL MEDICAL CENTER
BETHESDA, MARYLAND

30 December 1943

COMPARISON OF RATES OF DARK ADAPTATION UNDER RED ILLUMINATION AND IN TOTAL DARKNESS

Research Project X-218

Investigation and Report by

R. H. LEE
Lieutenant Commander, H-V(S), USNR

APPROVED:

A. R. BEHNKE
Commander, (MC), USN
Research Executive

E. G. HAKANSSON
Captain, (MC), USN
Commanding

The opinions or conclusions contained in this report are those of the author(s). They are not to be construed as necessarily reflecting the views or the endorsement of the Navy Department. Reference may be made to this report in the same way as to published articles noting author(s), title, source, date, project number and report number

OBJECT

To determine whether or not red light is better than total darkness in accelerating dark adaptation.

SUMMARY

It has been reported that the light adapted eye adapts to darkness more quickly if exposed to a red visual field of about 0.3 millilamberts intensity than if left in complete darkness for the same period of time. The thresholds at the end of twenty minutes exposure to red light followed by fifteen minutes of darkness were reported to be lower than after the same total period in darkness without red light exposure. The present studies do not confirm this statement.

In our experiments light adapted subjects were intermittently exposed to red visual fields at three low intensity levels and their thresholds recorded after each exposure.

Light adapted subjects were also exposed for twenty minutes to a red visual field of 0.3 millilamberts intensity followed by threshold measurements.

Control tests in complete darkness run under identical conditions were paired with the red light exposure tests.

CONCLUSION

No measurable accelerating action was found to result from exposure to red light. Thresholds obtained after red light exposure, are on the average higher than, or equal to, the corresponding thresholds following exposure to complete darkness.

INTRODUCTION

Night landing operations and bombing operations, lookout duty on ships and night fighting have emphasized the importance of exact information concerning night vision. Individuals engaged in those operations must be able to see under very dim lighting conditions, i.e., they must have low terminal thresholds of light and form perception, and must recover rapidly after exposure to lighted instruments, maps, etc.

The human eye can adapt itself to see details throughout a tremendous range of brightness. For example, a piece of white paper illuminated by direct sunlight may have a brightness as high as 6,000 to 8,000 millilamberts, whereas reading may be comfortably performed within the brightness range of 3 to 200 millilamberts. Furthermore on a dark night an object can be seen by a keen observer if it has a brightness of only 0.000005 millilamberts. Very large detail can be seen against a background at a somewhat higher level, say 0.00001 millilamberts. If the eye, adapted to see at the higher brightness, is plunged into darkness, objects at the lowest brightness levels will be invisible until one-half hour or more has elapsed. The course of dark adaptation may be followed by determining the minimal perceptible brightness at any instant, under constant conditions of fixation and test field area (8).

The human eye is populated by two kinds of sense endings, the rods and cones, which have very different characteristics (4, 5, 11, 12). The cones detect color difference (6) and see fine detail (7, 13), but are insensitive in the lower brightness ranges. The rods begin to function below 0.1 millilamberts. They do not detect color differences and can only resolve large detail. Night vision thus depends on the rods.

Because of the displacement towards the violet end of the spectrum of the rod luminosity curve relative to the cone luminosity curve, red light has much less effect on the rods than white light of equal photometric* intensity (3,9,10). (See Fig. 1). This also means that the process of dark adaptation is less disturbed by red light than by white light. On the other hand, tasks such as reading, which use cone vision, can be performed as readily under the red light as under white light of equal photometric intensity (1,3,4,15,16).

---

*By definition, photometric units are based on the cone luminosity curve.

It has been reported recently by British investigators (2) and by Miles (14) that red light has an accelerating effect on the rate of dark adaptation. Terminal thresholds were also reported as being lower after red light exposure than after the same period in complete darkness. This appears to conflict with present concepts regarding the visual process and suggests a "specific" action of red light.

The present investigation was undertaken to determine whether it is necessary to modify our concepts. Military practice regarding night vision is based on prevailing concepts and may need revision should this new concept prove correct.

DESCRIPTION OF APPARATUS AND METHODS OF MEASUREMENT

Experimental room.- The room in which the subjects wait to be tested contains the dark adaptometer and experimental booth. It is illuminated entirely by artificial light from ceiling and desk units. This illumination is not uniform due to visible lighting units, differences in color and reflectances of walls, ceiling, and fixtures.

The ceiling units of this room have a surface brightness of about 620 millilamberts while some of the black surfaces of the adaptometer present a brightness under 0.15 millilamberts. Hence a specification of the lighting conditions would be impossible.

Experimental booth.- The experimental booth extends into the laboratory room from an alcove. This alcove has been walled off and is light proof but well ventilated. The alcove end of the booth is painted black. While being tested, the subject sits in this section of the booth with his chin on a chin rest, his right hand controls the brightness of the adaptometer test field and the left hand a signal button.

A window immediately in front of the subject permits him to look into the front section of the booth. He can also reach into this section and turn the pages of a book or magazine on a reading stand just beyond the window.

The front section of the booth which contains the test field is painted white. It can be lighted by means of 10 ruby safety lamps located near the top of the booth, 5 along each side and baffled in such manner as to give a uniform brightness to all parts of the front section of the booth. The front section can also be lighted by a white 200 watt tungsten lamp. This illumination is greater on the reading stand than elsewhere by a ratio of 2 to 1.

Dark adaptometer.- The fixation pattern which consists of 5 small red dots forming a 2 inch centered square is located against the front wall of the booth.

The test field is vertically below the fixation point.

The dimensions of the test equipment are as follows:

Test field to subject - 52 inches
Test field diameter - 2 3/4 inches = 3° 2'
Fixation point to test field - 5⅛ inches = 6° 2'

The test field is an opal glass plate illuminated by a photocell exciter lamp rated at 10 volts, 7.5 amperes but operated at 6.95 amperes. The source is about 80 inches behind the screen. The light from this source is interrupted continuously by a sector disk having seven sectors which give equal light and dark phases. This disk is mounted on the shaft of the reduction gear of a synchronous motor, motor speed 1800 R.P.M., reduction gear 200 to 1.

The brightness is controlled by neutral glass filters and wedge. The subject has a knob at his right hand by means of which he changes the wedge position.

Calibrations.- Wedge and filters are calibrated for density by means of a Bausch and Lomb polarizing photometer. The upper brightness of the test field is about 0.3 millilamberts without neutral filters, as measured with a Macbeth illuminometer. The lower operating brightnesses are calculated from this figure and the densities of the wedge and filters.

Both brightnesses are measured with a Macbeth illuminometer. A filter whose transmission is known for the color temperature of the Macbeth working lamp permits measurement of rod light brightness.

Technique of testing.- The dark adaptation measurements are taken with the subject seated in the rear booth, chin on chin rest.

The operator signals to the subject by means of a bell at about 5 seconds before the minute and half minute. The subject then fixates the center dot of the fixation pattern and turns his brightness control until the test field is barely visible. He signals the operator who records the wedge reading. The subject then increases the brightness of the test field to "scramble" the setting and turns down the brightness control until he can no longer see the test

field. This wedge setting is then recorded. The whole procedure requires less than 10 seconds. The two wedge readings (just visible and just out) are averaged and the mean value translated into log I units (I is in micro-microlamberts) by means of a table previously prepared. Measurements are taken every 1/2 minute while testing. The subject relaxes between each set of readings in order to avoid fatigue.

Subjects.- The subjects used in this test were trained corpsmen furnished by the Naval Medical Research Institute, the principal investigator, designated as Le in the tables and an assistant Fi.

EXPERIMENTAL RESULTS

SERIES I.

Intermittent exposures to red light.- Exposures to red light were made at several brightnesses. These exposures were interrupted periodically in order to measure the dark adaptation thresholds. Control tests alternated with exposure tests.

Plan of tests:

Duration (min.)	Tests with Red Light Exposure	Control Tests
10 or more	Under room illumination	Under room illumination
15	Enter booth with 44 ml. (white) on reading stand	Enter booth with 44 ml. (white) on reading stand
Time (min.)	Stop watch started	Stop watch started
0	White light off; red light on	White light off
0-10	Red light	Darkness
10-15	Threshold measured every ½ minute in darkness	Threshold measured every ½ minute in darkness
15-20	Red light	Darkness
20-25	Threshold measured every ½ minute in darkness	Threshold measured every ½ minute in darkness
25-30	Red light	Darkness
30-35	Threshold measured every ½ minute in darkness	Threshold measured every ½ minute in darkness

Treatment of data.- Each subject's mean performance during the control tests has been subtracted from his mean performance during the rod exposure tests and these differences tabulated, i.e. Log I (red) minus Log I (control) where I is the intensity in micro-microlamberts. The mean differences for the group are tabulated in the last column of each table.

Table I.- Four subjects were exposed to red light at 0.87 millilamberts. Each subject received two red exposure tests and two control tests.

Figure 2.- The original data from which Table I was constructed have been averaged and are plotted in Figure 2. This figure will enable the reader to visualize the relationship between the tables and the original data. The last column of Table I may be obtained by subtracting ordinate values on the lower curve of Figure 2 from the Corresponding values on the upper curve of that figure.

Table II.- Four subjects were exposed to red light at 0.28 millilamberts. Each subject received four red exposure tests and four control tests.

Table III.- Four subjects were exposed to a red light of very low intensity (below range of Macbeth illuminometer) estimated to be about 0.001 millilamberts. Each subject received six red exposure tests and six control tests.

SERIES II.

Continuous exposure to red light of 0.3 millilamberts intensity.- Exposures to red light were made at a single brightness of 0.3 millilamberts. Control tests alternated with exposure tests.

Plan of tests:

Duration (min.)	Tests with Red Light Exposure	Control Tests
10 or more	Under room illumination	Under room illumination
15	Enter booth with 6.9 (white) millilamberts on reading stand	Enter booth with 6.9 (white) millilamberts on reading stand
Time (min.)	Stop watch started	Stop watch started
0	White light off; red on	White light off
0-20	Red light 0.3 ml.	Darkness
20-40	Thresholds measured every ½ minute in darkness	Thresholds measured every ½ minute in darkness

Treatment of data.- Same as in Series I.

Table IV.- Six subjects were exposed to red light at 0.3 millilamberts. Each subject received three red exposure tests and three controls.

Figure 3.- The original data from which Table IV was constructed have been averaged and are plotted in Figure 3. See explanation on page 6 of Figure 2.

DISCUSSION

1. Examination of Tables I and II shows conclusively that exposure to a red light of these intensities (0.87 and 0.28 ml.) raises the threshold appreciably above that to be found in complete darkness at the corresponding instants. This occurs whenever the red light exposure is introduced.

2. The data of Table III were obtained from red light exposures at the cone threshold of light perception. Many of the differences are negative indicating that the red exposure thresholds were lower than the corresponding control thresholds. The magnitudes are, however, insignificant and the differences are undoubtedly due to chance.

3. The data of Table IV were obtained under conditions chosen in order to duplicate the British experiments. It is again evident that red light delays the recovery of dark adaptation.

4. No basis has been found for the belief that red light hastens the recovery of dark adaptation. The evidence presented here confirms the generally accepted hypothesis concerning the action of red light on dark adaptation as explained in the introduction to this paper.

ACKNOWLEDGMENTS

We wish to acknowledge our indebtedness to the Division of Industrial Hygiene, National Institute of Health, U. S. Public Health Service, who supplied the space and quipment used in this study; Principal Biologist Harold F. Blum, Naval Medical Research Institute; Lieutenant A. P. Webster, H-V(S), USNR, Research Section, Bureau of Medicine and Surgery, for their many valuable suggestions, and to Scientific Aide Elizabeth M. Finch, National Institute of Health, U. S. Public Health Service; G. A. Pounds, PhM2c and M. A. Pittman, PhM1c, for their administration of the tests and aid with the data, as well as their cooperation as subjects; to J. T. DiAngelo, PhM3c and C. A. Stevens, PhM3c for their cooperation as subjects.

REFERENCES

1. Blum H. F.: Photodynamic Action and Diseases Caused by Light. Reinhold Publishing Corporation, New York, 1941.
2. British Confidential Report: Toddington. TA-394-25/A/RL/N6/0/360.
3. Hartline, H. K.: Relative Merits of Lights of Different Wave Lengths in Aircraft Cockpit Illumination. C.A.M. Report No. 10, 1941 (Confidential).
4. Hecht, S.: La Base Chimique et Structurale de la Vision. Hermann et Cie, Paris, 1938.
5. Hecht, S.: The Nature of Foveal Dark Adaptation. J. Gen. Physiol. 4:113, 1921.
6. Hecht, S.: The Interrelation of Various Aspects of Color Vision. J.O.S.A. 21:615-639, 1931.
7. Hecht; S. and Mintz, E. U.: The Visibility of Single Lines at Various Illuminations and the Retinal Basis of Visual Perception. J. Gen. Physiol. 22:593-612, 1939.
8. Hecht, S. and Shlaer, Simon: An Adaptometer for Measuring Human Dark Adaptation. J.O.S.A. 28: July 1938.
9. Hecht, S. and Williams, R. E.: The Visibility of Monochromatic Radiation and the Absorption Spectrum of Visual Purple. J. Gen. Physiol. 5:1, 1922-23.
10. Hyde, E. P., Forsythe, W. E. and Cady, F. E.: The Visibility of Radiation. J. Franklin Inst., 185: 829, 1918.
11. Kohlrausch, A.: Untersuchungen Mit Farbigen Schwellenprufflichtern Uber den Dunkeladeptationsverlauf des Normalen Auges. Arch. f. d. ges. Physiol., 196: 113, 1922.
12. Von Kries, J.: Ueber die Funktion der Netzhautstabchen. A. Psychol. und Physiol. Sinnesorgane, 9:81, 1895.
13. Luckiesh, M. and Taylor, A. H.: A Summary of Researches in Seeing at Low Brightness Levels. Ill. Eng., 38:189-207, 1943.
14. Miles, Walter K.: Red Goggles Producing Dark Adaptation. Federal Proceedings, 2:109-115, 1943.
15. Solandt, D. Y. and Best, C. H.: Night Vision. Canadian Med. Association Journal, 49: 17-21, 1943.
16. Weinbach, A. P. and Lee, R. H.: C.A.M. Report No. 46, 1942.

Table I.

Relative Effect on Dark Adaptation of Red Light of 0.87 Millilamberts as Compared with Total Darkness
Log I (Red) - Log I (Darkness)

Time (min.)	Fi	Pi	Po	Wi	Mean	Remarks
10.5	.88	.69	.42	.61	.65	
11.0	.39	.51	.15	.53	.40	Time is reckoned from the instant the white, preadapting light is turned off.
11.5	.62	.55	.25	.34	.44	
12.0	.56	.46	.13	.29	.36	
12.5	.35	.26	.06	.28	.24	
13.0	.22	.28	.03	.31	.21	
13.5	.25	.30	.06	.09	.18	In the red exposure tests, the subject views the red light during the following periods:
14.0	.19	.21	.09	.08	.14	
14.5	.36	.34	.04	.10	.21	
	Red Light or Darkness					0 to 10 minutes 15 to 20 minutes 25 to 30 minutes
20.5	.65	.66	.85	.25	.60	
21.0	.38	.60	.55	.45	.47	
21.5	.26	.42	.43	.27	.35	
22.0	.34	.36	.24	.12	.27	In the control tests the subject sits in darkness during the same periods, without taking readings. The numbers in the body of the table are the differences between the red exposure test readings and the control test readings expressed in log units.
22.5	.26	.30	.33	.25	.29	
23.0	.14	.29	.25	.17	.21	
23.5	.02	.25	.31	.19	.19	
24.0	.30	.26	.33	.23	.28	
24.5	.20	.24	.28	.30	.26	
	Red Light or Darkness					
30.5	.58	.38	.98	.51	.61	
31.0	.32	.37	.81	.30	.45	
31.5	.27	.40	.61	.13	.35	
32.0	.49	.32	.53	.29	.41	
32.5	.34	.38	.49	.25	.37	
33.0	.38	.23	.40	+.10	.28	
33.5	.30	.34	.51	-.10	.26	
34.0	.10	.38	.44	.04	.24	
34.5	.28	.30	.40	.16	.29	

Table II

Relative Effect on Dark Adaptation of Red Light of 0.28 Millilamberts as Compared with Total Darkness
Log I (Red) - Log I (Darkness)

Time (min.)	Fi	Pi	Po	Wi	Mean	Remarks
10.5	.67	.58	.40	.38	.51	
11.0	.41	.35	.17	.47	.35	Time is reckoned from the instant the white, pre-adapting light is turned off.
11.5	.41	.18	.41	.24	.31	
12.0	.41	.27	.31	.25	.31	
12.5	.34	.28	.27	.20	.27	
13.0	.19	.23	.22	.10	.19	
13.5	.31	.14	.25	.14	.21	In the red exposure tests, the subject views the red light during the following periods:
14.0	.30	.12	.26	.04	.18	
14.5	.10	.24	.33	.15	.21	
Red Light or Darkness						0 to 10 minutes 15 to 20 minutes 25 to 30 minutes
20.5	.54	.44	.78	.25	.50	
21.0	.35	.31	.50	.18	.34	
21.5	.16	.30	.54	.12	.28	
22.0	.22	.10	.48	.07	.22	In the control tests, the subject sits in darkness during the same periods, without taking readings.
22.5	.12	.06	.32	.23	.18	
23.0	.06	-.06	.38	.09	.12	
23.5	.08	-.04	.21	-.03	.06	
24.0	.05	.19	.32	0	.14	
24.5	.21	.10	.40	.07	.19	The numbers in the body of the table are the differences between the red exposure test readings and the control test readings expressed in log units.
Red Light or Darkness						
30.5	.62	.39	.86	.47	.59	
31.0	.38	.23	.71	.10	.36	
31.5	.23	.15	.69	.07	.29	
32.0	.12	.09	.58	.01	.20	
32.5	.09	.16	.52	.03	.20	
33.0	.06	.06	.48	.16	.19	
33.5	.18	.16	.43	.17	.24	
34.0	.20	.20	.49	.19	.27	
34.5	.30	.15	.56	.26	.32	

Table III

Relative Effect on Dark Adaptation of Red Light of Very Low Intensity as Compared with Total Darkness

Log I (Red) - Log I (Darkness)

Time (min.)	Fi	Le	Po	Pi	Mean	Remarks
10.5	.05	-.03	-.03	.02	0	
11.0	.06	-.06	-.06	.03	-.01	
11.5	-.04	-.10	-.08	-.04	-.07	
12.0	-.04	-.02	-.02	-.01	-.02	
12.5	-.09	-.06	-.06	.04	-.04	
13.0	-.04	-.01	.02	.02	0	
13.5	.15	.04	-.10	-.03	.02	
14.0	.14	-.03	-.13	0	-.01	
14.5	.17	-.04	-.17	-.04	-.02	
Red Light or Darkness						
20.5	-.10	0	.07	.12	.02	
21.0	-.06	-.07	.01	.06	-.02	
21.5	-.09	-.01	0	.05	-.01	
22.0	-.02	.04	.01	.05	.02	
22.5	.07	-.04	0	.04	.02	
23.0	.13	-.08	-.06	-.03	-.01	
23.5	.08	-.01	.04	-.06	.01	
24.0	.02	-.06	-.02	.03	-.01	
24.5	.05	-.04	-.02	-.07	-.02	
Red Light or Darkness						
30.5	.02	.06	.10	-.01	.04	
31.0	.06	.03	-.05	-.03	0	
31.5	.03	-.03	-.03	0	-.01	
32.0	0	-.05	0	-.02	-.02	
32.5	-.02	0	.01	.01	0	
33.0	.08	-.07	0	.04	.01	
33.5	.10	-.07	-.01	-.19	-.04	
34.0	.05	.04	-.04	-.16	-.02	
34.5	.06	-.02	-.07	.03	0	

Time is reckoned from the instant the white, pre-adapting light is turned off.

In the red exposure tests, the subject views the red light during the following periods:

0 to 10 minutes
15 to 20 minutes
25 to 30 minutes

In the control tests, the subject sits in darkness during the same periods, without taking readings.

The numbers in the body of the table are the differences between the red exposure test readings and the control test readings expressed in log units.

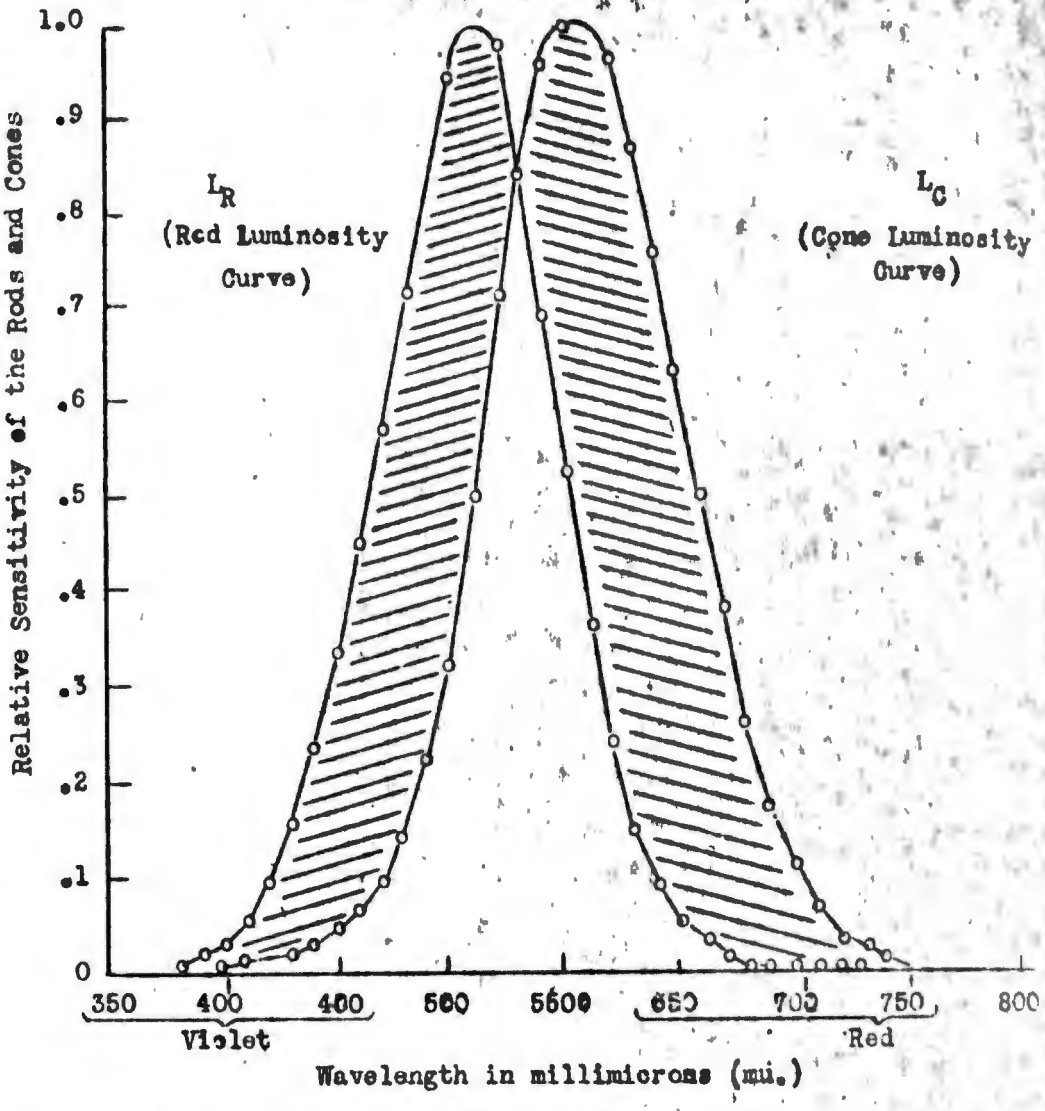
Table IV

Relative Effect on Dark Adaptation of Continuous Exposure for Twenty Minutes to Red Light of 0.3 Millilamberts as Compared with Total Darkness

Log I (Red) - Log I (Darkness)

Time (min.)	Di	Fi	Le	Pi	Po	St	Mean	Remarks
20.5	.78	.89	1.01	.59	.91	.71	.82	
21.0	.63	.69	.81	.45	.69	.56	.64	Time is reckoned
21.5	.62	.63	.63	.37	.63	.38	54	from the instant the
22.0	.61	.53	.54	.28	.57	.35	.48	white, preadapting
22.5	.58	.41	.43	.29	.60	.29	.43	light is turned off.
23.0	.44	.27	.36	.27	.43	.26	.34	
23.5	.28	.34	.26	.24	.57	.17	.31	In the red exposure
24.0	.26	.23	.29	.20	.56	.29	.31	tests, the subject
24.5	.32	.24	.21	.15	.55	.36	.31	views the red light
25.0	.36	.19	.24	.06	.49	.40	.29	during the first
25.5	.35	.30	.23	.10	.53	.38	.31	twenty minutes.
26.0	.19	.21	.27	.16	.43	.37	.27	
26.5	.23	.29	.28	.23	.43	.28	.29	In the control tests
27.0	.24	.29	.38	.03	.43	.45	.30	the subject sits in
27.5	.26	.22	.33	.08	.38	.43	.28	darkness during the
28.0	.31	.26	.35	-.04	.36	.28	.25	same period, without
28.5	.34	.18	.31	.06	.40	.14	.24	taking readings.
29.0	.02	.24	.30	.13	.41	.20	.22	
29.5	.03	.13	.28	.13	.41	.24	.20	The numbers in the
30.0	.05	.16	.19	.11	.24	.17	.15	body of the table
30.5	.15	.13	.22	0	.42	.12	.18	are the differences
31.0	.21	.16	.22	.09	.34	.16	.20	between the red ex-
31.5	.17	.22	.11	.04	.39	.20	.19	posure test readings
32.0	.11	.17	.10	.10	.30	.15	.16	and the control test
32.5	.02	.25	.06	.10	.39	.13	.16	readings expressed
33.0	.07	.04	.03	.08	.38	.10	.12	in log units.
33.5	.08	.06	.11	.01	.37	.14	.13	
34.0	.08	.18	.09	.08	.33	.09	.14	
34.5	.13	.14	.16	-.05	.25	.12	.13	
35.0	.07	.17	.07	-.01	.30	.11	.12	
35.5	.01	.15	.11	-.14	.33	.11	.10	
36.0	.05	.17	.07	-.01	.36	.09	.12	
36.5	.10	.22	.06	-.06	.22	.09	.11	
37.0	.01	.20	.05	.04	.22	.01	.09	
37.5	.07	.19	.01	-.09	.16	.02	.06	
38.0	-.01	.14	.09	-.08	.16	.05	.06	
38.5	-.08	.15	.16	-.10	.15	.08	.09	
39.0	.09	.05	.14	-.07	.14	.05	.07	
39.5	.09	.07	.09	.11	.18	.13	.11	
40.0	-.01	.04	.13	.02	.17	.09	.07	
40.5	.07	-	.04	-.04	.25	.06	.08	

Fig. 1 RELATIVE LUMINOSITY CURVES
(From A.S.A., RO 43, 15 June, 1942)



The shaded area to the left indicates the sprectral region in which the rods are relatively more sensitive than the cones.

The shaded area to the right indicates the sprectral region in which the rods are relatively less sensitive than the cones.

The ordinates are arbitrarily chosen to bring both maxia to the same value.

If two lights of wavelength λ_1 and λ_2 are of equal intensity as seen by the cones, the double ratio:

$$\frac{L_C(\lambda_2)}{L_R(\lambda_2)} \times \frac{L_R(\lambda_1)}{L_C(\lambda_1)}$$ is a measure of how many times brighter the first light is than the second as seen by the rods.

854

Fig. 2 THE COURSE OF DARK ADAPTATION
(mean of several tests)
o = Intermittent Exposures to Red Light (0.87 millilamberts)
Δ = Control tests

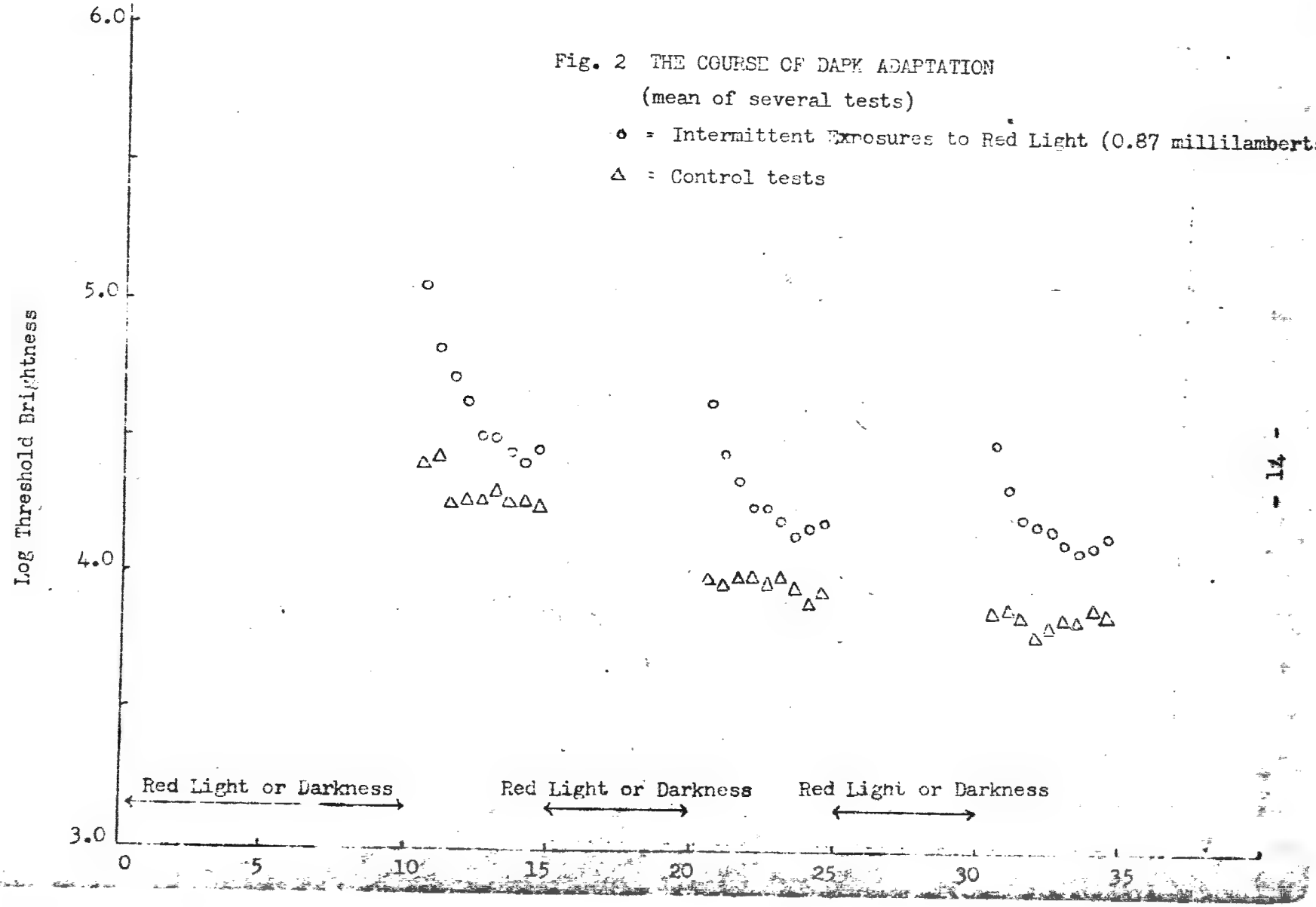


Fig. 3 THE COURSE OF DARK ADAPTATION
(mean of several tests)

o = 20 minutes red light @ 0.3 millilamberts

Δ = Control - 20 minutes total darkness